

Transverse optical mode in a one-dimensional Yukawa chain*

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Strongly-coupled dusty plasmas have much in common with pure-ion plasmas and ion-storage rings. Charged particles can be:

- trapped indefinitely in a confinement device
- formed into a 3D suspension, a 2D monolayer, or a 1D chain
- arranged in a periodic phase
- imaged directly, allowing a measurement of position of individual particles
- manipulated by the radiation pressure of laser light.

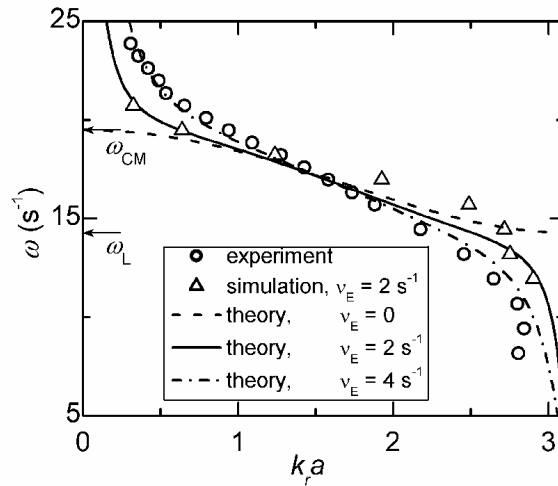
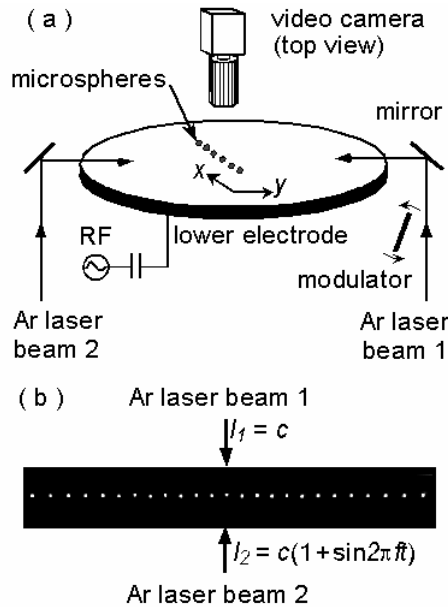
A dusty plasma is, however, different in some respects: particles are charged by collecting electrons and ions, they interact with a Yukawa repulsion, and they move slowly.

In an experiment, a 1D chain was formed by levitating a single row of charged microspheres above a groove in a lower electrode. The confining potential was harmonic in all three directions, but with vastly different bounce periods in each direction. At the center of chain, two counter-propagating laser beams were used to manipulate a single particle, pushing it perpendicular to the chain, thereby exciting a transverse wave, which we term the transverse optical mode.

In this wave, particle displacement is restored by a harmonic confining potential due to the groove. Because particles repel one another, the mode is backward, i.e., frequency decreases with wave number, and the group and phase velocities are oppositely directed.

We measured the transverse optical wave's dispersion relation for chains of three different lengths. We verified that the wave is backward, and we tested a theoretical dispersion relation.

Gas damping has a large effect on the dispersion relation. Without damping, the wave is unable to propagate outside an allowed frequency band between two cutoff frequencies ω_L and ω_{CM} . Here, ω_{CM} corresponds to a sloshing of the entire chain. With damping, the wave can propagate a short distance for frequencies outside the band. *Work supported by DOE and NASA



Temperature Measurements of Laser-Cooled Ions in a Penning Trap¹

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Up to $\sim 10^6$ $^9\text{Be}^+$ ions are trapped in a 4.5 Tesla Penning trap and laser-cooled down to temperatures below 10 mK where the ions form a crystal with an interparticle spacing of about $20\text{ }\mu\text{m}$ [2]. We have measured the temperature and heating rate of the trapped and laser-cooled $^9\text{Be}^+$ ions. This work is primarily motivated by the possibility of creating many-particle entangled states. Such states would have applications in the fields of both quantum information and frequency standards. To date, experiments in miniature RF-traps have entangled the hyperfine ground states of up to 4 ions [3].

We measure the temperature by Doppler laser spectroscopy on a single-photon transition in $^9\text{Be}^+$. Fig. 1 shows the recorded temperature as a function of time after turning off the cooling laser. At $t = 0$, we measure $T \sim 1\text{ mK}$ which is close to the Doppler cooling limit. A slow heating rate of less than 100 mK/s is observed for $t < 200\text{ ms}$. This heating rate is comparable to the heating rates observed in the miniature RF-traps typically used for ion-entanglement experiments. Studies in which the residual gas pressure was varied indicate that this short-time heating is due to collisions with the room temperature residual gas. The slow heating is followed by a sudden, rapid heating on the order of 2 K/s . The onset of rapid heating occurs when the coupling parameter decreases to a value lower than the value associated with the solid-liquid phase transition, $\Gamma \sim 170$. We therefore believe that this feature is a manifestation of the solid-liquid phase transition. However, at this time we do not understand the cause of the rapid temperature increase in the liquid state. The energy increase appears to be too large to be accounted for by any external heating sources (background gas collisions, external fields, etc.) and may therefore more likely be attributed to conversion of potential to thermal energy possibly caused by a slight expansion of the ion cloud.

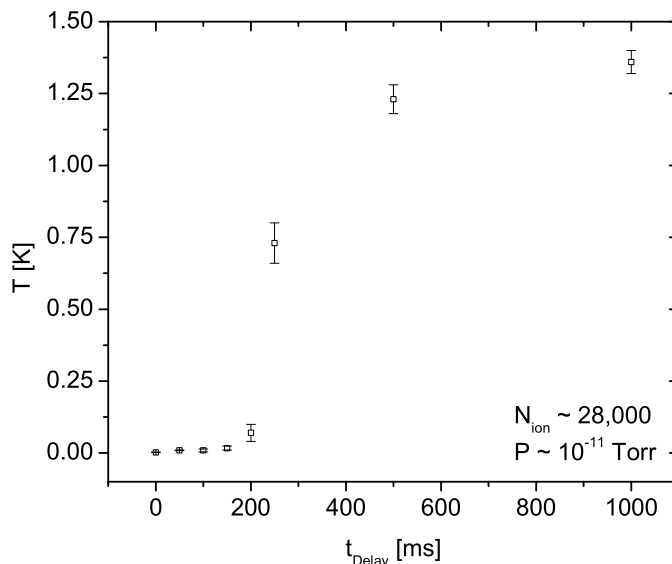


Figure 1: Heating rate measurements for a spherical cloud consisting of 28,000 ions. This measurement is carried out at our normal base pressure $\sim 10^{-11}$ Torr.

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[2] W. M. Itano, J. J. Bollinger, J. N. Tan, B. M. Jelenkovic, X.-P. Huang, and D. J. Wineland, *Science* **279**, 686 (1998).

[3] C. A. Sackett, D. Kielpinski, B. E. King, C. Langer, V. Meyer, C. J. Myatt, M. Rowe, Q. A. Turchette, W. M. Itano, D. J. Wineland, and C. Monroe, *Nature* **404**, 256 (2000).

Static and dynamically excited structures of single- and two-component Coulomb crystals

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We present the first experimental evidence for three-dimensional long-range-ordered structures of single-component ion Coulomb crystals in rf traps. The findings, obtained by laser cooled $^{40}\text{Ca}^+$ ions in a linear Paul trap, are supported by molecular dynamics (MD) simulations recently performed by us, and show a substantially different dependence on the number of ions than observed in earlier long-range-ordered studies in Penning traps [1,2].

We also present dynamically excited stable single-component crystal-like structures in a linear Paul trap created either by applying a torque induced by the radiation pressure force from an off-axis laser beam as often applied in Penning trap experiments [3], or by operating the trap beyond the line of stability for parametric excitation of plasma modes [4,5].

With respect to two-component systems, we present experimental results on singly charged near-equal mass bi-crystals of $^{40}\text{Ca}^+$ - $^{44}\text{Ca}^+$ ions, where the ions are simultaneously or alternately laser cooled. Similarities and differences between these bi-crystals and previously investigated $^{24}\text{Mg}^+$ - $^{40}\text{Ca}^+$ crystals [6] will be discussed.

Finally, theoretical investigation of cold two-component Coulomb systems of particles with the same charge-to-mass ratio confined in a spherical potential will be considered. By a series of MD simulations with up to 10^6 particles, we have shown how the two species mix completely, independent of the relative ratio of the two species, on a length scale larger than an effective Wigner-Seitz radius, which can be defined for such systems. For finite systems with an equal amount of the two types of particles, we furthermore show that the ground state in general consists of a simple cubic structured core (with one of each species as a base pair) surrounded by a series of double shells [7].

- [1] W. M. Itano, J. J. Bollinger, J. N. Tan, B. Jelenkovic, X.-P. Huang, and D. J. Wineland, *Science* **279**, 686 (1998).
- [2] T. B. Mitchell, J. J. Bollinger, D. H. E. Dubin, X.-P. Huang, W. M. Itano, and R. H. Baughman, *Science* **282**, 1290 (1998).
- [3] J. J. Bollinger and D. J. Wineland, *Phys. Rev. Lett.* **53**, 348 (1984).
- [4] M. Drewsen, I. S. Jensen, N. Kjærgaard, J. Lindballe, A. Mortensen, K. Mølhave, and D. Voigt, *J. Phys. B: At. Mol. Opt. Phys.* **36**, 525 (2003).
- [5] N. Kjærgaard and M. Drewsen, submitted for publication.
- [6] L. Hornekær, N. Kjærgaard, A. M. Thommesen, and M. Drewsen, *Phys. Rev. Lett.* **86**, 1994 (2001).
- [7] T. Matthey, J. P. Hansen, and M. Drewsen, submitted for publication.

Recent studies on the charge-state conversion of anions by electron-bathing in a Penning trap

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In an effort to extend the field of gas-phase metal clusters (small particles consisting of a few up to a few hundred atoms) we have recently introduced a method to increase the charge state of mono-anions stored in a Penning trap [1]. To this end an electron ensemble is stored simultaneously with the clusters. Several features of these experiments have already been discussed, in particular with respect to the properties of the clusters under investigation [2]. In this contribution we focus on two aspects concerning the electron ensemble.

Electron attachment occurs in the time range of seconds with an exponential behaviour and an offset on non-reacting precursor clusters (see Fig. 1), tentatively explained as follows: In order to attach further electrons to the clusters which are already negatively charged, the electrons need sufficient kinetic energy to overcome the repulsive Coulomb barrier. The initial radial (cyclotron) motion is cooled rapidly by radiation of the revolving electrons. The axial motion is not cooled as fast by radiation but may be coupled to the radial motion. Thus, the experimental time constants are a measure of the coupling between the cyclotron and the axial modes.

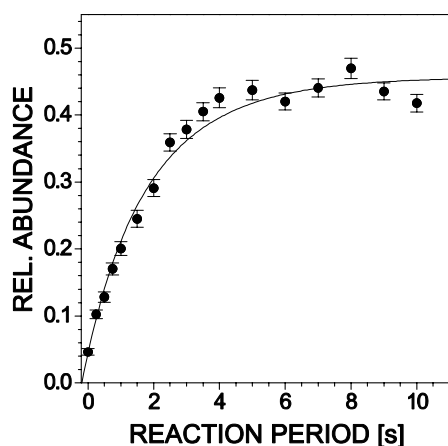


Fig. 1: Relative abundance of dianions as a function of the reaction period in the electron bath.

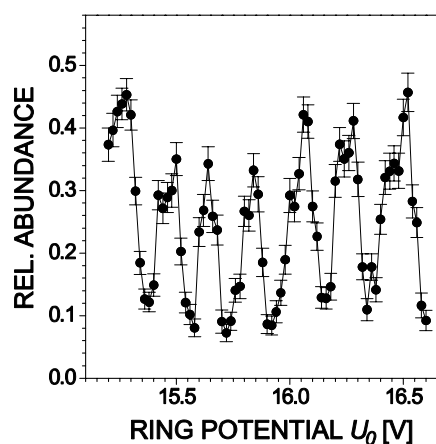


Fig. 2: Relative abundance of dianions as a function of the applied ring potential.

In addition to the temporal behaviour a distinct pattern is found in the charge-state-conversion yield as a function of the axial trapping voltage (see Fig. 2). There is strong evidence that the observed dips of the dianion yield are related to the frequency ratio of the magnetron motion and the ions' cyclotron motion, possibly a coupling between the electrons' and ions' motional modes.

- [1] A. Herlert et al., *Physica Scripta* T80, 200 (1999); A. Herlert et al., *Int. J. Mass Spectrom.* 218, 217 (2002)
- [2] L. Schweikhard et al., *Philos. Mag. B* 79, 1343 (1999); C. Yannouleas et al., *Phys. Rev. Lett.* 86, 2996 (2001)

Abstract Submitted
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Modeling Intense Beam Propagation in the Paul Trap Simulator Experiment¹ ERIK P. GILSON, RONALD C. DAVIDSON, PHILIP C. EFTHIMION, RICHARD MAJESKI, AND EDWARD A. STARTSEV, Princeton Plasma Physics Laboratory — The Paul Trap Simulator Experiment (PTSX) is a compact laboratory facility whose purpose is to simulate the nonlinear dynamics of intense charged particle beam propagation over large distances through an alternating-gradient transport system. The PTSX device is a 200 cm long, 20 cm diameter cylindrical Paul trap in which a 400 V, 100 kHz signal confines cesium ions to an rms radius of 1 cm. Experiments performed on emittance-dominated cesium plasmas in which the repulsive self-electric force is smaller than the repulsive thermal pressure force are in good agreement with a robust model that balances these outward forces with the confining inward force of the PTSX electrodes. The one-component cesium plasmas can be confined for hundreds of milliseconds, which would correspond to an equivalent alternating-gradient transport system tens of kilometers long. The normalized intensity parameter $s = \omega_p^2 / 2\omega_q^2$, where ω_q is the average transverse focusing frequency, describes whether the plasma is emittance-dominated ($s \ll 1$) or space-charge-dominated ($s \sim 1$). By increasing the amount of charge loaded into the trap, PTSX reaches values of $s = 0.7$. Thus, the opportunity exists to study important physics topics such as: the conditions necessary for quiescent intense beam propagation over large distances, beam mismatch and envelope instabilities, collective mode excitations, the dynamics and production of halo particles, emittance growth, compression techniques, and the effects of the distribution function on stability properties. This paper presents detailed experimental studies showing the dependence of the transverse density profile and rms plasma radius on the intensity parameter s and the hold time t_h for the charge cloud. Comparisons with 3D particle-in-cell simulations are also presented.

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☒ Prefer Oral Session
☐ Prefer Poster Session

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Coherent Structures in Low Energy Electron Beams in ELTRAP

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The formation and evolution of coherent structures in an electron plasma are investigated in the Malmberg-Penning trap ELTRAP, operating in the beam configuration, where a low energy electron plasma continuously flows from the emitting thermionic cathode to a collector (phosphor screen), held at a potential of few kV, and the diocotron frequency is controlled by varying the magnetic field. The electron density distribution at the screen is measured via the CCD diagnostic. The observed nonlinear processes are interpreted using fluid models and a recently developed 3D PIC code, and are compared with the measurements made on the ELTRAP confined plasma, with the inject-hold-dump technique.

As a development of the above research, a different ELTRAP configuration is in progress (ELETRASP experiment, I.N.F.N.), where a pulsed (4 ns, 5 keV, 0.1 nC) electron source is used, and the CCD diagnostic allows the investigation of plasma effects (e.g., wave-breaking) in the beam. These phenomena, in relativistic laminar beams produced by photo-injectors at higher energy (150 MeV) severely limit the brightness achievable, which is of great relevance in many applications, like X-ray SASE-FELs. Their experimental investigation is very difficult owing to the small width of the beam (100 μ). We aim to measure such effects in ELTRAP, on beams with quite lower energy (few keV), but with the same properties (as far as the transverse dynamic is concerned) of the relativistic beams: this is possible if the plasma frequency is kept constant while the current is properly scaled with the beam energy and spot size, so that the beam envelope follows the same behavior with a much larger spot size (few mm).

Non-destructive positron plasma diagnostics for antihydrogen production

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Abstract

Production of antihydrogen atoms by mixing antiprotons with a cold, confined, positron plasma depends on parameters such as the plasma density and temperature. We discuss a non-destructive diagnostic, based on an analysis of excited, low-order plasma modes, that provides comprehensive characterization of the positron plasma in the ATHENA antihydrogen apparatus. The dipole and quadrupole modes of a spheroidal positron plasma are interpreted in the framework of a cold fluid theory. In particular, the excitation and detection of the dipole mode are analytically modeled considering the response of the center-of-mass in correspondence of a resonant driving perturbation. The model is compared and validated by numerical simulations with a particle-in-cell code. Measurements of the positron plasma properties during antihydrogen production experiments are discussed.

Numerical non-neutral plasmas

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For the past 15 years, or so, a set of computational tools for studying non-neutral plasmas has been developed at Brigham Young University. These codes, which include equilibrium codes (for both static plasmas and solitons), radial eigenvalue codes, 2-d eigenvalue codes, and both 2-d and 3-d particle-in-cell simulation codes, will be discussed, along with their applications to problems of interest to the non-neutral plasma physics community.